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PHASE LOCKED FREQUENCY MULTIPLIER FOR A SPEED - AND PHASE SYNCHRONIZATION SYSTEM BETWEEN A d.c.- AND A SYNCHRONOUS MOTOR

by

F. MAY

1966

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Department
Experimental Neutron Physics

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The first and the sixth pulses of the output pulse train are phase locked to the reference pulses. Maximum phase deviations do not exceed a few microseconds.

The multiplier is realized by means of a multivibrator which is controlled by a phase detector.

In connection with the frequency multiplier a phase control system for the synchronous motor is pointed out. Any phase relation between d.c.- and synchronous motor could be achieved by adjusting the mechanical angle of the pick-up system mounted on the synchronous motor. The phase control system has not been realized.

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SUMMARY

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1. INTRODUCTION

A synchronizing system for synchronization between a dc- and a synchronous motor has been designed for a neutron rotating crystal spectrometer* installed at the ISPRA - I reactor of the EURATOM center at Ispra (Italy).

A simple chopper, which is driven by the synchronous-motor should suppress neutrons of unwanted energies (higher orders, neutrons reflected by parasitic reflection planes) in the neutron beam produced by the rotating crystal . Out of hystorical background the rotating crystal is driven by a speed controlled dc - motor. If the speed of the motors is stable enough, the time of flight of the neutrons from the crystal to the chopper can be simulated by a certain phase ralation. Because of the transmission function of the chopper the phase deviations should not exceed $\pm$ 5-10 μsec.

A speed synchronizing and phase stabilizing driving system for the synchronous motor has been developed already by the reactor electronics department at Ispra which will be described elsewhere.

This system needs 12 trigger-pulses per revolution at the input to generate a rotational field.

As the magnetic pick-up system of the dc - motor delivers only two reference pulses per revolution, it was necessary to derive a timing pulse train of 12 pulses per revolution from only two. Of course the generated pulse train has to be phase locked with the reference pulses.

Regardless of the existing control system mentioned above, there will be pointed out a rather simple control system in connection with the frequency multiplier, but which not yet has been realized.

* description not yet published

2. PHASE LOCKED FREQUENCY MULTIPLIER :

2,1. Principle of operation : (fig. 1.)

By the pick-up system of the dc - motor (crystal) there are available two reference pulses per revolution. The speed of the dc - motor is stabilized within a few ‰ by means of a speed control unit [1]. Normally the motor is set to turn with a speed of 6000 r p m. (= 100 c p s).

Occurring phase pendulum of the motor in an amount of ± 10-20 μsec could be suppressed completely by a simple trick, just by connecting an appropriate resistor in series to the power supply of the rotator. (damping)

Such, remaining a time jitter of at least one μ-sec the two pulses generated by the magnetic pick-up system can serve as synchronizing marks.

To get the wanted number of pulses per revolution (in our case 12 = 1,2 kc per sec) an astable multivibrator is adjusted to the appropriate frequency. The output pulses of the multivibrator are counted down by a frequency divider to give two pulses per revolution.

The synchronizing marks and the two output pulses of the frequency divider are compared by means of a phase detector. The phase errors are integrated and a d-c amplifier serves as control unit of the multivibrator.

2,2. Phase detector : (fig. 2,3,4,5)

The phase detector is a rather simple device. Assume that "a" is the input coming from the dc - motor (reference) and "b" the input coming from the frequency devider which is fed by the multivibrator (controlled by the phasedetector).

The input pulses of each input "a" and "b" are divided by two, by means of two flip-flops A and B respectively. C is an auxiliary switch, which enables a two-time comparison every revolution (every incoming pulse).

The positive shot of A sets and the negative shot of B resets the switch C. As seen by fig. 2 the two commands "faster" and "slower" for the multivibrator are given by the two formulas respectively :

$$\text{faster} : f = (A\bar{B} + \bar{A}B)\, C$$

$$\text{slower} : s = (A\bar{B} + \bar{A}B)\, \bar{C}$$

As one can see by the two expressions, a command has to be given every time when A and B are different. The decision between the commands "faster" and "slower" is done by the auxiliary switch C. Realisation of the logical functions can be done by a simple logical device shown in fig. 5 (taking into account also the forbidden input functions, the expressions would become simpler but it would not reduce the number of elements).

The widths of the output pulses of the phase detector are corresponding to the phase error. The 180° uncertainty given by the flip-flops A and B are irrelevant because of the 180° symmetry of the transmission function of the chopper.

As the phase errors should be in the range of μsecs or less, the switching time of logical elements is designed to be relatively short (50 nsec).

2,3. Amplifier (fig. 6)

For stability reasons the amplifier is choosen as to be a differential amplifier supplied with a temperature compensated transistor (T_3 = 2N 2060). The input pulses (phase errors delivered by the phase detector) are differentiated to prevent the amplifier from beeing overloaded by large phase errors. The two transistors T_1 and T_2 serve as switches to load the integrating capacitors C_1 and C_2 by means of "slower" and "faster" commands respectively. The integrating time constant has to be much larger than the sampling time distance of 5 m sec to ensure a sufficient smooth dc controlling current for the multivibrator. On the other hand the time response of the whole circuit should not be unnecessarily slow. Therefore the integrating time constant is about 100 m sec.

The amplificationfactor Δi dc current/$_{\Delta t}$ input pulse width can easily be varied by changing the emitter resistors of T_1 and T_2. (within certain limits i is linearly depending on t).

The potentiometers P_2 and P_1 serve for adjustment of the amplifier dc balance and the frequency of the multivibrator respectively.

2,4. Multivibrator (fig. 7)

The multivibrator is a conventional device, except that the discharging current (that means the frequency) of the coupling capacitors C_1 and C_2 is controlled by the amplifier, which is described in chapter 2,3. As the frequency fo of the multivibrator is a linear function of the discharging current, the frequency deviation Δf is proportional to the phase error pulse width (see chapter 2,3). One can easily understand that the multivibrator as concerning frequency and phase, can be locked with a given reference pulse train. The only conditions one has to take care of are : the multivibrator has to be adjusted to the proper frequency. (reference frequency times frequency multiplication factor; for variable reference frequency the current generator T_4 in fig. 6 should be controlled by a simple ratemeter circuit); the frequency divider (fig. 1) has to divide by a factor, which is equal to the wanted frequency multiplication. Besides one has to take care of the general principles of a closed loop sampling system.

The multivibrator in connection with the dc amplifier is designed to give minimum frequency deviations depending on temperature and dc voltage variations (+25V, -12V: $\frac{\Delta f}{f} / \frac{\Delta V}{V} = \pm 2\% / \pm 10\%$)

(temperature dependence negligible between 25° C and 40° C; general principles are described elsewhere [2].)

The two diodes D_7 and D_8 in fig. 7 are limiting the frequency deviation of the multivibrator to $\Delta f / f_o = \pm 6\%$. For this reason the separating stages T_4 and T_5 are necessary. (If the dc-balance of the amplifier is adjusted properly, point P_1 and P_2 have the same potential). The diodes D_5 and D_6 enable the multivibrator to give output pulses (with a little bit lower frequency) in any case, (except the positive supply voltage is missing or there is some fault in the multivibrator itself), even if all other cards are disconnected. This precaution is made for security reasons for the driving unit of the synchronous motor.

2.5 <u>Closed loop; operating instructions</u> : (fig. 6,8)

Driving the whole circuit with closed loop, the multivibrator of course is synchronized to the incoming reference pulses. At 6000 r p m of the dc - motor the sampling time distance is 5 m sec. The position of every 6th pulse of the multivibrator is compared with the position of the incoming reference pulses. As the multivibrator is frequency synchronized to the reference pulses any deviation in frequency of the multivibrator or the dc-motor is converted into phase errors.

The converting factor (phase errors given in μsecs) of

$\Delta\varphi / \frac{\Delta f}{f} = 2\,\mu\mathrm{sec}/1\%$ is very low.

Such the dependence on the dc supply voltage is not more than

$\Delta\varphi / \frac{\Delta V}{V} = 4\,\mu\mathrm{sec}/10\%$ for either + 25 V and - 12 V.

The influence of temperature is negligible small and is not larger than half a μ sec within a temperature range of 25° to 40° C.

The longterm stability could not yet be measured, but one can assume that the overall phase deviations should not exceed a few μ secs, even for a time period of say a few weeks, if the circuit is adjusted properly.

The adjusting procedure is very simple :

Before operating, the dc - balance of the amplifier has to be checked with inputs "a" and "b" being disconnected. (see fig. 6,8; the switch mounted on the front panel being in "check" position, the potentials of P_1 and P_2 should not differ more than 100 mV). In addition to, the frequency of the multivibrator should be adjusted to be as near as possible to the closed loop operating frequency, but in any case within $\pm$ 5%. By switching to the operate position the loop is closed and at the check points on the front panel appear the phase error signals. Now the frequency of the multivibrator (P_1) can be adjusted for minimum phase error signal.

As the reference input pulses are not free of a certain jitter (phase variations of 1 - 1,5 μsec) of course the output pulses of the multivibrator are infected with jitter too, but not more 1 - 1,5 μsec.

3. <u>PHASE CONTROL SYSTEM</u> (fig. 9)

As the phase relation between dc - motor (crystal) and synchronous motor (chopper) should corresponde to the time of flight of the neutrons from the crystal to the chopper, for a given neutron energy the phase between crystal and chopper has to be changed if the energy of the neutron is changed.

To be independent of speed variations of the crystal the time of flight of the neutrons should be simulted by a delay unit, which is adjustable corresponding to the time of flight of neutrons with desired energies. Besides a phase control system would be necessary to compensate phase pendulum of the synchronous motor and its longterm phase deviations. On the other hand, if the speed of the motors is stable enough (1‰ is sufficient) the time of flight of the neutrons can be simulated by a fixed phase relation between crystal and chopper. In this case the relatively expensive digital delay unit could be spared.

A phase control system which allows to realize any phase relation within 360 degrees between crystal and chopper is shown in fig. 9.

The univibrators I and II are adjusted to delay 90 degrees each (=2,5 msec). As one can imagine, the influence of univibrator II is such, that the phase shift caused by univibrator I is compensated. The output pulses of the multivibrator are in phase with the reference pulses of the dc motor. If the univibrators I and II are driven into apposite directions (differential amplifier) the phase shift of both is added. That means that a phase shift of ± 45 and ∓ 45 degrees of the univibrators would cause a phase shift of ± 90 degrees of the output of the multivibrator. To get ± 180 degrees phase shift, the univibrators should be variable by a value of ± 90 degree. This difficulty can be avoided by switching over the phase detector by a value of 180 degrees if the phase error signal exceeds 90 degrees. This easily can be done by feeding an additional pulse to the phase detector input, which, by means of a coincidence circuit, is derived from the phase detector error signal and 90 degree pulses of the frequency divider (3^{th} and / or 9^{th} pulse). Any a phase relation between dc -and synchronous motor can be achieved by revolving its pick-up system, which is mounted such, that any angle within 360 degrees can be adjusted. To avoid the synchronous motor falling out of synchronism the univibrators I and II should be driven very slowly (about 10 secs per 360 degrees). This can be done by a small motor, which is able to turn in both directions.

For compensating the phase pendulum(± 10 - 20 μsec) of the synchronous motor a third univibrator III with small delay can be used. The time response of this circuit (amplifier + univibrator III) should be rather fast (say 100 m sec) to be fast enough compared with pendulum frequency (0,5-1 cp sec) of the motor. If by the phase error signal the amplifier is driven to one of its limits (e.g. ± 10 μsecs) the corresponding schmitt-trigger should drive the small motor till symmetry of the amplifier is reached again.

4. CONCLUSION

Besides the described solution for a synchronizing system there are existing other possibilities. A rather simple solution would be to drive the synchronous motor by means of the free running multivibrator. If the frequency of the multivibrator is adjusted according to the speed of the dc-motor (by hand or automatically), the described phasedetector and the amplifier could be used to control the dc-motor by superimposing the phase error signal to the dc-reference voltage of the speed control unit. It would be necessary to have a proper damping of the synchronous motor.

The damping problem would not exist if two dc-motors would be used. (see introduction). On the other hand, fast running dc-motors also can cause a lot of troubles (collector).

Using two synchronous motors at this moment was out of question, because an extensive mechanical rebuilt of the apparatus would have been necessary.

5. SUMMARY

A phase locked frequency multiplier (6 times) is described, which is designed for the purpose of a synchronizing system between a dc- and a synchronous motor. Maximum phase deviations are in the order of a few μsecs while the sampling time distance is 5 msec. Drawings of the circuits are given in detail.

Besides, a phase control system for the synchronous motor has been pointed out, but which not has been realized.

It has been pointed out that the described system is perhaps not the simplest one being possible but one of the possible solutions regarding the gradually completion of the apparatus and the available equipments.

ACKNOWLEDGMENTS :

This work is based on a work which has been done in the reactor-electronics department at Ispra and is done as a support. It would not have been possible to do it without getting informations and support by the department.

Especially I would kike to point out, that the frequency divider used in this circuit is designed by Mr. H. Brak. I thank Mr. Eder for the allowance to do this work in the laboratories of the reactor electronics department and to use the equipments and material.

LITERATURE :

The used speed control unit has been designed by:

1) D. Roebbelen and A. Strub. Private communication

2) H. Halling, F. May. Univibrator as time base element in a medium fast coincidence circuit.
Nucl. Instr. a . Meth. in print.

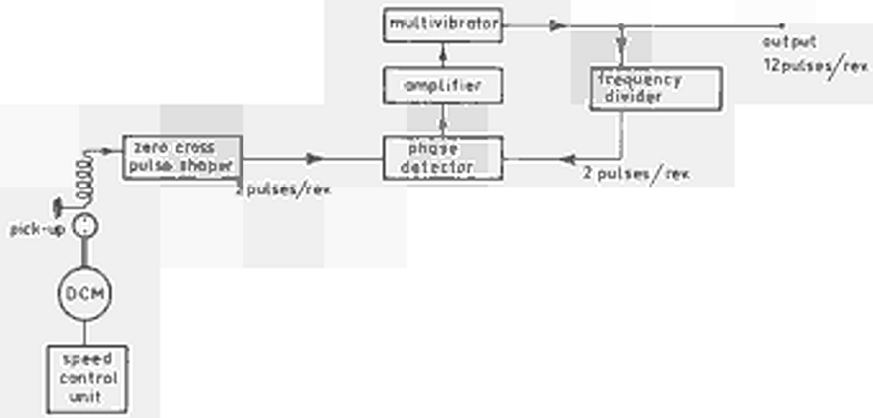

Fig. 1 : BLOCK DIAGRAM OF THE FREQUENCY MULTIPLIER.

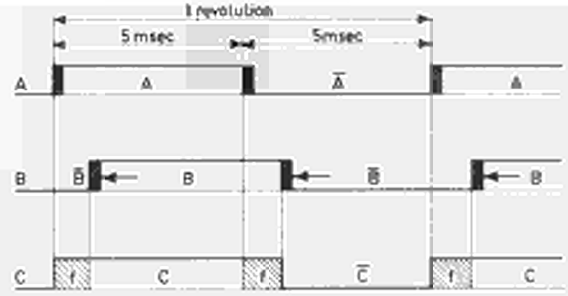

Fig. 2a : DEMONSTRATION FOR COMMAND „FASTER"

$f = A\bar{B}C + \bar{A}BC = (A\bar{B} + \bar{A}B)C$

Fig. 2b : DEMONSTRATION FOR COMMAND „SLOWER"

$S = A\bar{B}\bar{C} + \bar{A}B\bar{C} = (A\bar{B} + \bar{A}B)\bar{C}$

Fig. 2 : DEMONSTRATION OF OPERATING PRINCIPLE OF THE PHASE DETECTOR.

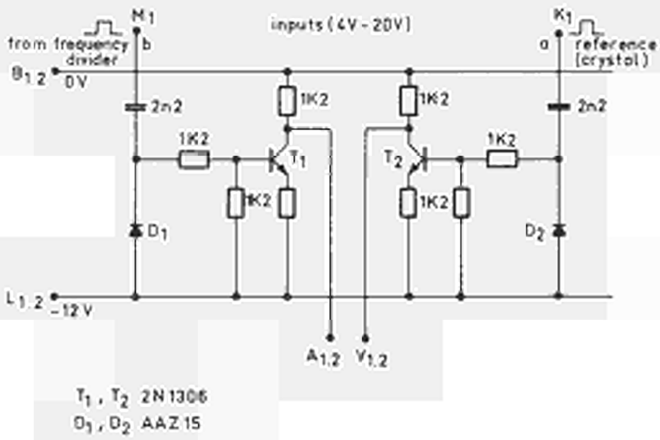

Fig. 3 : PHASE DETECTOR; INPUT PULSE SHAPER; CARD 1

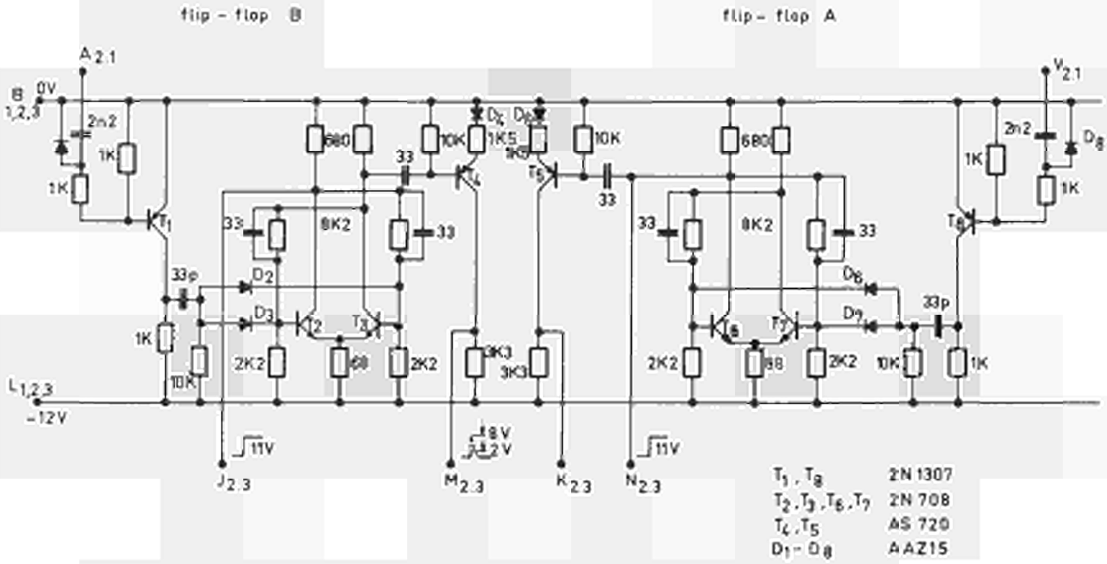

Fig. 4 : PHASE DETECTOR; FLIP-FLOP A and B; CARD 2

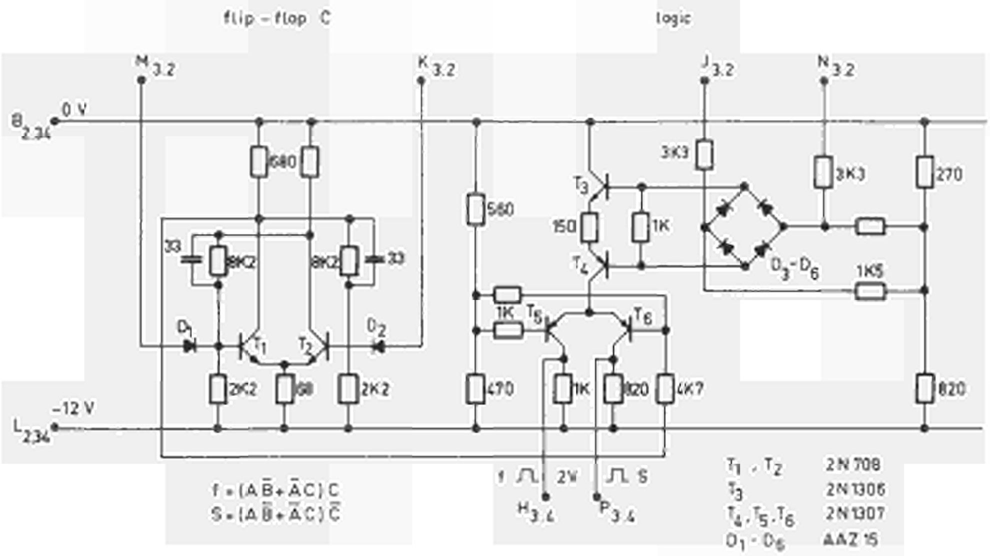

Fig. 5 : PHASE DETECTOR ; FLIP-FLOP C ; LOGIC ; CARD 3

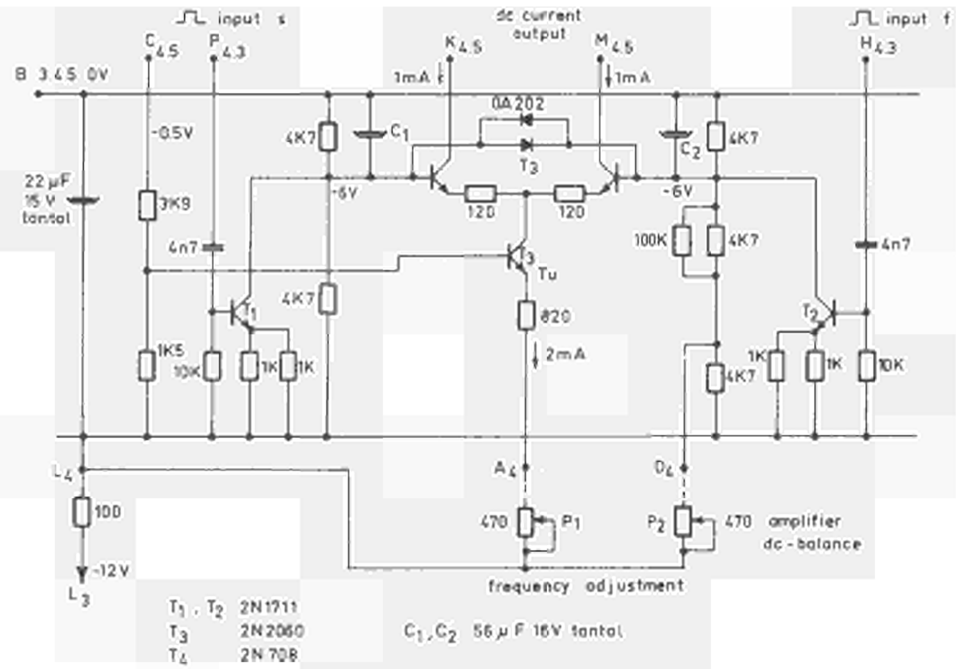

Fig 6 : AMPLIFIER, CARD 4

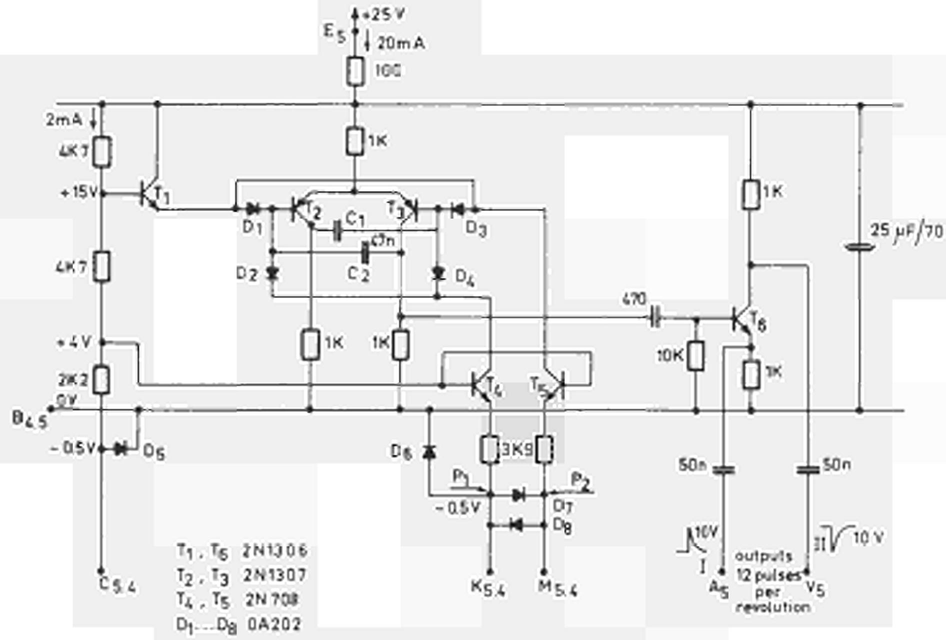

Fig. 7 : MULTIVIBRATOR, CARD 5

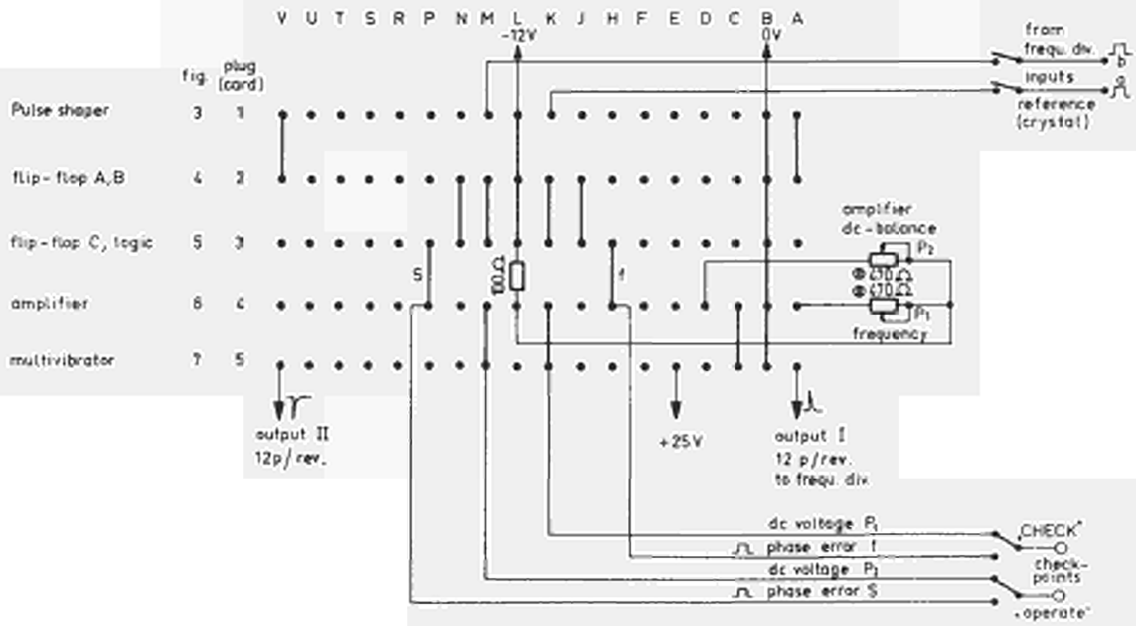

Fig. 8 : WIRING SCHEME OF PLUGS.

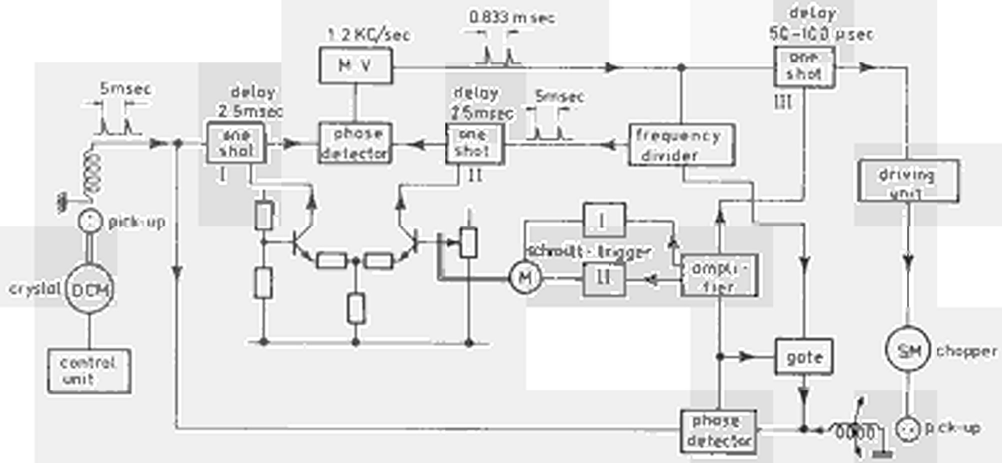

Fig. 9 : SPEED SYNCRONIZING AND PHASE CONTROL SYSTEM BETWEEN A DC-AND A SYNCHRONOUS MOTOR.

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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